Solutions for Hydrogen-Induced Delayed Fracture in Hot Stamping

Hongzhou Lu[1, 5,a],Shiqi Zhang[2,6,b*], Bian Jian[3,c], Hardy Mohrbacher[4,d] and Aimin Guo[1,e]

[1]CITIC Metal Co., Ltd., Beijing 100004, China
[2]College of Mechanical Engineering，Yangtze University, Jingzhou 434023, China
[3]Niobium Tech Asia, 068898 Singapore
[4]NiobelCon bvba, 2970 Schilde, Belgium
[5]The School of Resources and Environmental Engineering, East China University of Science and Technology, Shanghai 200237, China
[6]School of Materials Science and Engineering, University of Science and Technology , Beijing 100083, China
[a]hongzhoulu@foxmail.com, [b]tryzsq@163.com, [c]jian.bian@niobiumtech.com, [d]hm@niobelcon.net, [e]guoam@citic.com

[*] Corresponding author: Zhang Shiqi, email: tryzsq@163.com

Keywords: Hot stamping; Hot press forming; Hydrogen induced delayed cracking; Niobium microalloying; Safety; Solutions

Abstract. One of the main targets in automotive industry is to reduce the weight of vehicle as well as increase the safety. To accomplish this goal, press-hardening steel and hot stamping parts have been used in car body. However, the possibility of hydrogen-induced delayed fracture (HDF) of hot stamping parts exits, which will decrease the car's passive safety. A solution has been presented to reduce the sensitivity of HDF and improve hydrogen-induced delayed fracture resistance (HDFR) by Niobium micro-alloying technology. Traditional press-hardening steel 22MnB5 and new steel 22MnBNb2, 22MnBNb5 and 22MnBNb7 were studied, and it is shown that the appropriate addition of Nb is beneficial to the improvement of the delayed fracture resistance of the hot stamping steel, which indicates that Niobium micro-alloying technology is an effective solution to the HDF in hot stamping steels.

Introduction

Improvement of safety, reduction of energy consumption, and reduction of emission become ones of the most highlighted issues for automotive industry in recent years. One of the most significant solutions, i.e. lightweight engineering by application of new materials and process has been discussed and described for a long time. Over the last decade, hot press forming process has become a key lightweight technology for the automotive industry worldwide because it offers ultra-high strength up to 1500MPa for the safety components and lightweight engineering, and adopting the modern manufacturing technology to form the ultra-high steels and finally gives carmakers new opportunities to achieve the lightweight design. The application weight ratio of hot stamping parts is up to 26% in the car body[1], and According to the estimation by VOLVO, PHS could reach a weight contribution of 40% in the car body application in the near future [2]. According to the estimation currently there are about 190 production lines worldwide with a total capacity of 285 million components each year[3]. There are more than 40 production lines including built HPF lines and building lines in China. In the future press hardening steel will continue to grow for the lightweight application in the car body. Generally, the application of press-hardening steel and hot stamping parts in car body is capable to reduce the weight of vehicle as well as increase the safety. However, the potential problems exist endangering the crash behavior of hot stamping parts due to high sensitivity to HDF. For example, an investigation from Lovicu [4] shows that already a few ppm of hydrogen charged into the press hardening steel will dramatically deteriorate its strength, and delayed cracking can be a consequence of this strength deterioration. When the press-hardening steel is smelted, hot rolled and austenitized, the hydrogen could get into the steel, and when hot press forming parts are welded, and when the car with hot press forming parts is used by costumers, the hydrogen could get into the components. Once the hydrogen content in components is more than some critical value, the components will crack at low stress. Such a delayed cracking is no doubt to reduce the car’s passive safety. So we will discuss the solution for these big issues in this paper.

Experimental

The chemical composition (wt.%) of the investigated material is shown in Table 1, thereinto, traditional press-hardening steel 22MnB5 is as the corresponding steel, and which is commonly used now, and 22MnBNb2, 22MnBNb5 and 22MnBNb7 are new developed steel based on 22MnB5, which represents for the steel with niobium content of 0.02, 0.05, 0.07 wt.% respectively. The plate samples were forged from ingots and followed by hot rolling and cold rolling process. Then the specimens were heated up into austenite region at 930°C, held for 3 min, and deformed while water quenching.

Table 1 Chemical compositions of experimental steels（wt%）

Steel	C	Si	Mn	Ti	Cr	B	Nb
22MnB5	0.25	0.32	1.20	0.030	0.17	0.0022	—
22MnBNb2	0.24	0.33	1.17	0.031	0.16	0.0028	0.022
22MnBNb5	0.23	0.33	1.18	0.033	0.17	0.0025	0.053
22MnBNb7	0.23	0.31	1.29	0.029	0.20	0.0025	0.072

The diagrammatic sketch of constant load test is shown in Fig.1.

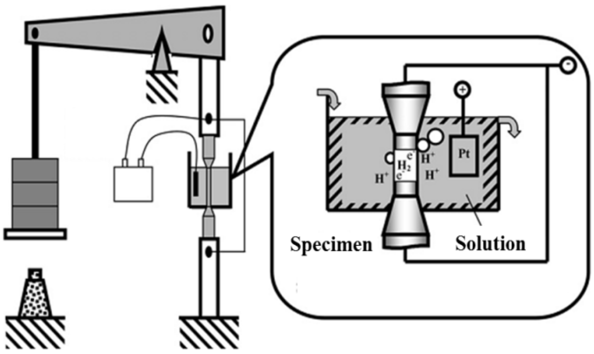
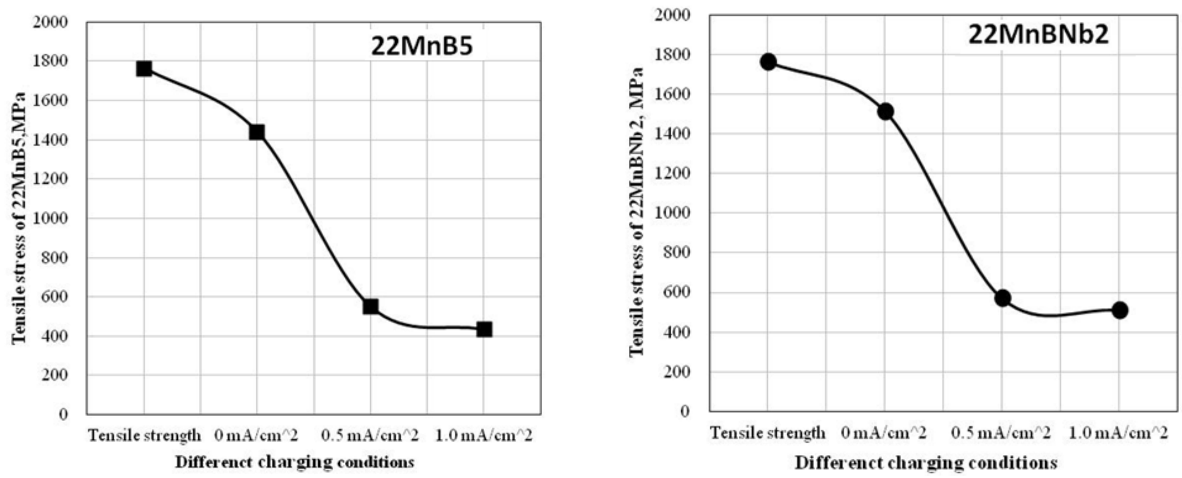


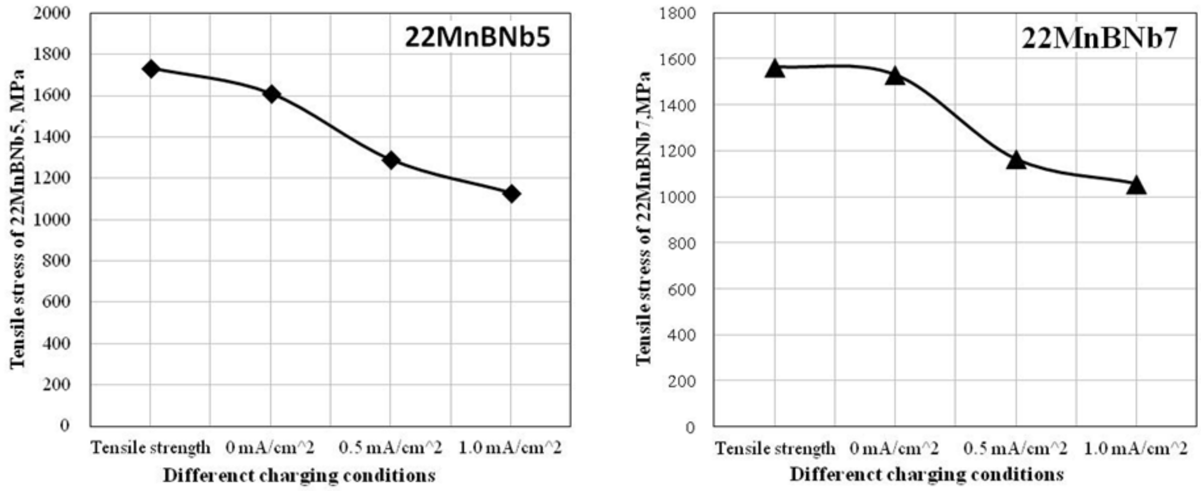
Figure 1 The diagrammatic sketch for constant load test

Results

Fig.2 shows the changes of critical delayed fracture stress σ_{HIC} of different press-hardening steel at various current densities (i) in the constant load tests. The σ_{HIC} of the steels in hydrogen charging condition have decreased to various extents. In Fig.2(a) and (b), with the increscent of current density, the critical delayed fracture stress decreased obviously, especially for 0.5 mA/cm^2.



(a) (b)



(c) (d)

Figure 2 The diagrammatic sketch for constant load test

However, in Fig.2(c) and (d), with the increscent of current density, the critical delayed fracture stress decreased, but the drop is only about 400MPa, even at 1.0 mA/cm^2.

Discussions

As mentioned above, when the press-hardening steel is smelted, hot rolled and austenitized, the hydrogen could get into the steel, and when hot press forming parts are welded, and when the car with hot press forming parts is used by customers, the hydrogen could get into the components. Fig 3 shows the potential process where the hydrogen could get into the steel or components.

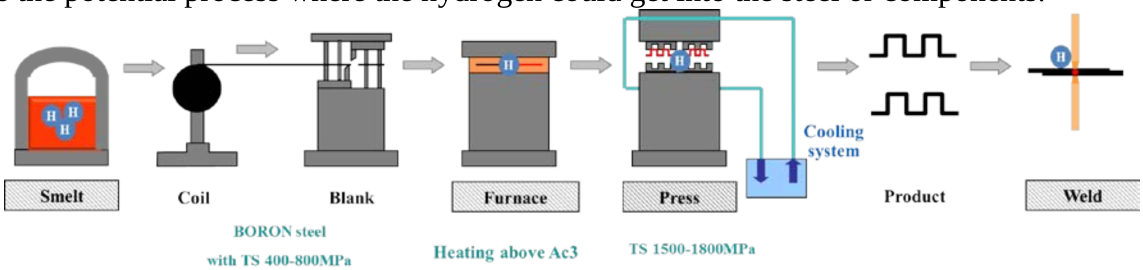


Fig 3 the potential process where the hydrogen could get into the steel or components

Acccording to the results of constant load test, we can perform the comparison of critical delayed fracture stress σ_{HIC} between 22MnB5 and 22MnBNb5, which is seen in Fig 4, and from Fig 4, we can find out that the difference of delayed fracture resistance is obvious at various un-charging conditions for 22MnB5 and 22MnBNb5. When the current density is 0.5mA/cm^2, the critical delayed fracture stress of traditional 22MnB5 decreases so much, and variation of reduction of delayed fracture strength of 22MnB5 is about 1000MPa, it means that a hydrogen-induced brittle fracture happens due to the hydrogen. However, when the current density is 0.5mA/cm^2, the critical delayed fracture stress of traditional 22MnBNb5 is about 1300MPa, and variation of reduction of delayed fracture strength of 22MnB5 is only about 400MPa. From the Fig 4, when the current densities are 0mA/cm^2, 0.5mA/cm^2 and 1.0mA/cm^2, the difference of delayed fracture resistance for 22MnB5 and 22MnBNb5 are 200MPa, 750MPa and 700MPa respectively. In a word, the addition of Nb improves the HDFR.

In addition, many studies show that grain refinement reduces the delayed fracture resistance of steel[9]. Nb, as one of the important alloy additives of high-strength steel, is widely used because of its distinct effect on the grain refinement of metal. In this work, The dispersive distribution of the fine Nb(C,N) particles in steels increase the effective area of grain boundary by reducing the grain size and thus enable the well-distribution of hydrogen trapping and inhibit the spread of hydrogen to the crack tip. Finally, the delayed fracture resistance of steel is improved by the improvement of the trap amount of grain boundary.

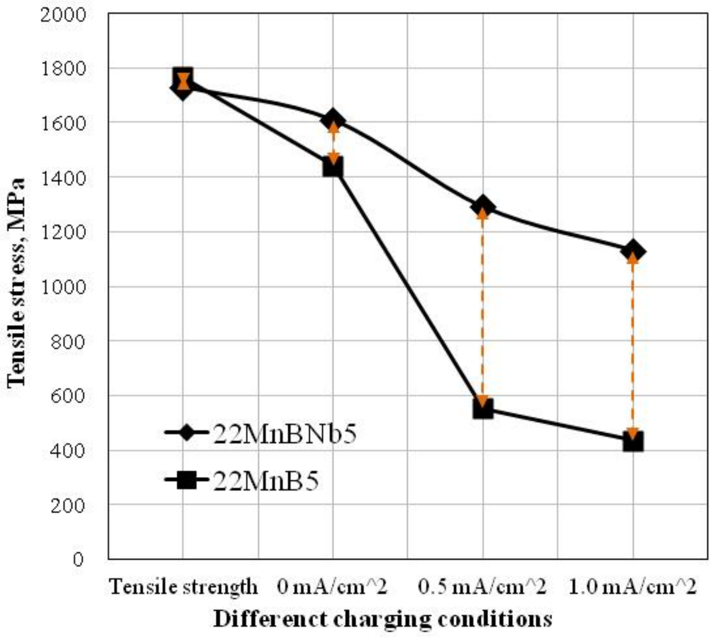


Figure 4 The comparison of critical delayed fracture stress σ_{HIC} between 22MnB5 and 22MnBNb5

Actually, in order to reduce the CO_2 emissions and fuel consumption, lots of Nb-containing steel has been used in automotive industry[10], in China, about 10 million tons Nb-containing steel have been used in automotive industry in 2013. And the Nb microalloying technology is a important way to improve the properties of high strength steel, for example, Nb microalloying technology can improve the strength, formability, toughness and weldability of auto steel simultaneously. The realization methods of reduce mass by application of Niobium alloying high strength steel can be seen in Table 2, by the application of Nb-containing HSS in vehicles, we can reduce thickness of parts, and optimize the geometry of parts to enhance the moment of inertia and improve the stiffness of parts, and also can reduce the carbon equivalent, and keep the strength, then reduce the welding cost and improve the qualification rate. Finally, we can reduce the car weight further. Just like that in this paper, press hardening steel has been used by the hot press forming to reduce the weight, but the hot press forming parts have lower bendability, and hydrogen induced delayed fracture is easy to happen for hot press forming parts due to the high strength, which are not good for the energy-absorbing and impact safety. When we apply the Niobium microalloying technology, both of the issues can be solved.

Table 2: The realization methods of reduce mass by application of Niobium microalloying high strength steel

Effect of Nb in auto steel	***High Strength Steel***	***How to reduce the weight***	***Assembly or parts***
Improve the strength	HSLA Dual-phase steel High Strength IF steel TRIP steel	Reduced thickness of parts	Car body
Improve the formability: Improve hole expanding Improve bendability	Dual-phase steel Multiphase steel Press hardening steel	Optimized the geometry of parts to enhance the moment of inertia, improved the stiffness of parts, and reduced thickness of parts	Car body Seat frame Wheels Chassis
Reduce the sensitivity of hydrogen embrittlement	Press hardening steel	Applied 1500MPa and 1800MPa hot press forming	Car body

	Martensite steel	parts, reduce thickness of parts	
Improve the weldability	Dual-phase steel Multiphase steel Press hardening steel TRIP steel	Reduced the carbon equivalent, keep the strength, then reduce the welding cost and improve the qualification rate	Car body Wheels
Improve the surface quality of coatings	Hot Dip Galvanized IF steel	Improved the qualification rate	Car body

Conclusions

(1) New press-hardening steel 22MnBNb2, 22MnBNb5 and 22MnBNb7 are studied, and 22MnBNb5 and 22MnBNb7 have better hydrogen delayed fracture resistance than traditional 22MnB5.

(2) The appropriate addition of Nb is beneficial to the improvement of the hydrengen delayed fracture resistance of high strength hot stamping steel.

(3) Niobium Microalloying Technology is a important solution for hydrogen-induced delayed fracture in hot stamping.

References

[1] Christian Bielz, Stefan Hein, Erhard Waltl, Audi- the new A3[C], Proc. of 14th Global Car Body Benchmarking Conference, Automotive Circle International, 2012, Bad Nauheim, Germany.

[2] “Inside Edition” Conference proceedings[C], Automotive Circle International, September 2011, Gothenburg.

[3] Hongzhou Lu, Bian Jian, Wenjun Wang, Aimin Guo.The Optimum Study of Hot Press Forming Technology based on Automotive Safety, Automobile Technology & Material, 2013,No.10, p7-13

[4] Lovicu G. et al., on Super High Strength Steels[C], Proc. of 2nd Int. Conf. Italy, 2010.

[5] Nagumo M, Takai K, Okuda N. Nature of hydrogen trapping sites in steels induced by plastic deformation[J]. Journal of alloys and compounds, 1999, 293: 310-316.

[6] Enos D G, Scully J R. A critical-strain criterion for hydrogen embrittlement of cold-drawn, ultrafine pearlitic steel[J]. Metallurgical and Materials Transactions A, 2002, 33(4): 1151-1166.

[7] Lee HG, Lee J Y. Hydrogen Trapping by TiC Particles in Iron[J]. Acta Metall, 1984, 32(1): 131-136.

[8] Pressouyre GM, Bernstein I M. An Example of the Effect of Hydrogen Trapping on Hydrogen Embrittlement[J]. Metall Trans, 1981, 12A(5): 835-844.

[9] Kimura Y, Takagi S, Hara T, et al. Hydrogen-induced delayed fracture of a martensitic steel with fine prior-austenite grain size[C]//Journal de Physique IV (Proceedings). EDP sciences, 2003, 112: 403-406.

[10] Lu Hongzhou,Li Jun, Chen Yilong, Guo Aimin, Wang Zhiwen, Wang Wenjun, Lu Guimin , Kao Chian Tou. Coupling Study of Fuel Consumption and Lightweight Objective of SUV Cars[C], FISITA 2014 World Automotive Congress, 2nd -6th June, Netherlands. F2014